Assessment of Technology for Mobile Offshore Base

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Abstract

A Mobile Offshore Base (MOB) is a very long floating platform comprised of interconnected modules. It will provide logistic support of United States' military operations where fixed bases are not available or adequate. As follow-on to previous ISOPE papers that described the technical research program and identified potential research spin-offs, this paper first identifies the major risk areas associated with technical feasibility. These risk areas include size, metocean conditions, connectors, global response, validated design tools, multi-body dynamic positioning, constructibility, design standards, survivability, and cargo transfer. The paper finishes with a general assessment about how technically feasible a MOB is today.

Key Words: Floating airfield, semisubmersible, classification guide, hydroelastic, stability, dynamic positioning, and connectors

Introduction

The concept of a Mobile Offshore Base (MOB) reflects the United States' need to stage and support military operations, including humanitarian operations, anywhere in the world. MOB is intended as a logistics facility that directly supports existing military assets, including aircraft carriers. MOB will provide a basing platform for marrying the troops to their materiel at a location very close to the area of conflict, but remain far enough away at sea to be easily defendable.

A MOB is a self-propelled, floating, prepositioned base that would accept cargo from airplanes and container ships and discharge resources to the shore via a variety of surface vessels and aircraft. There are two envisioned modes of operation. First, as independent semisubmersible modules, the MOB could provide logistic support for air (rotary wing or short take-off), land, and sea forces in several locations around the world at the same time. Second, serially-connecting multiple modules would form a long runway suitable for landing and takeoff of conventional fixed wing aircraft, including the Boeing C-17 cargo transporter.

For example, the three modules of Bechtel's independent module concept (Figure 1) must line up, to form a 1,500-m (5,000-ft) long straight runway for conventional fixed wing aircraft (Grant, et al., 1999). Runway and cargo drawbridges span the small gaps between the modules.

This modular approach allows for maximum flexibility and expandability. The individual modules are large enough to meet many basic mission needs as separate units, yet small enough to remain constructable in existing marine facilities and short enough to survive storms at sea. As defined by the National Research Council (NRC, 1991) the connected MOB is an innovative structure:

> *A structure that requires analysis and/or special fabrication and inspection controls beyond those required by existing rules. Moreover, an innovative structure is usually the first of its kind; few, if any, design standards directly apply and there is little operational experience to relate directly to the design review process. In the safety review of innovative structures, the identification of problem areas may be more important than the analysis itself, because by definition, the innovative structure may be subject to previously unknown load demands and failure modes.*

This innovative principle served as the basis for this ongoing Office of Naval Research (ONR) science and technology research program. The program focuses on four related product areas (Remmers and Taylor, 1998):

Figure 1. Bechtel's independent module concept.

- Composing a MOB classification guide
- Enhancing design/analysis tools
- Quantifying mission requirements and performance
- Advancing representative system concepts

Four major offshore contractors conceived MOB concepts to help establish feasibility, uncover technology problems, and support realistic cost estimating (Remmers, et al., 1998). Each of the four innovative concepts has fundamentally different degrees of module connectivity:

- *Compliant Hinge*: Five identical 305-m (1,000-ft) steel semisubmersibles connected using centerline ball joints and flexible edge connectors that allow the modules to pitch relative to one another (conceptualized by McDermott International).

- *Flexible Bridges*: Three 220-m (725-ft) steel semisubmersibles connected by two 430-m (1,410-ft) damped flexible bridges that act as distributed connectors to maintain a continuous flight deck (conceptualized by Kvaerner Maritime).

- *Elastomeric Bearings*: Four identical 380-m (1,250-ft) semisubmersibles with steel decks and concrete hull that use elastomeric bearing to connect modules into a straight runway (conceptualized by Aker Maritime).

- *Independent Modules*: Three identical 500-m (1,650-ft) steel semisubmersibles that rely principally on dynamic positioning to maintain relative close position between modules (conceptualized by Bechtel National).

Each semisubmersible module consists of a box type deck supported by multiple columns on two parallel pontoons. When on site, the module is ballasted down so that the pontoons are submerged below the surface wave zone. The columns provide a minimum exposed surface, thereby, minimizing wave loads. The decks, which store rolling stock and dry cargo, are all located above the wave crests. The columns provide structural support and hydrostatic stability against overturning.

Liquids are stored in the pontoons and columns, eliminating most below water voids and thus minimizing the danger of damage due to flooding. When transiting between operational sites, the unit is deballasted and travels with the pontoons on the surface much like a catamaran.

STANDARDS AND CRITERIA

The connected MOB will be the largest floating marine structure ever built. The available commercial and military design standards are largely based on experience. However, there is no past experience on floating structures as long and large as the MOB. In the absence of such experience, it is critical to return to engineering and scientific fundamentals, and to rely on expert opinion.

A special *MOB Design Guide and Commentary* (ABS, 1999) has been prepared and revised several times by the American Bureau of Shipping, working under the guidance of the MOB Standards and Criteria Working Group. The Working Group is composed of experts in government, commercial industry, and academia. The *Guide* is the first performance and reliability-based standard for floating ocean structures published in the United States.

The *Guide* provides a framework for the design processes, metocean criteria, stability limits, and survivability requirements necessary for preliminary and detail design of a MOB. The document is not yet complete, requiring the addition of reliability-based ocean and weather criteria and revised target reliabilities, estimates of uncertainty, and partial safety factors. These criteria will be set after satisfactory resolution of all critical risk areas described in the following paragraphs.

MAJOR RISK AREAS ADDRESSED

A number of critical risk areas associated with MOB feasibility were identified. During the brief 3-year history of this ONR MOB program, an attempt was made to quantify and resolve these risks in a parallel fashion (Remmers, et al., 1999). There was insufficient time to resolve all the critical risks, many of which require more time and serial execution. Below we summarize each major risk area, present some solutions, and highlight certain topics that remain for future research efforts.

MOB Length/Size

Length is the single most critical factor driving cost and technical risk. Most of the missions and capabilities can be supported by a single (or multiple disconnected) semisubmersible MOB module, which represents only a modest increase in risk over the current industry standard for large lifting semisubmersibles. However, the requirement to connect them into long runways capable of supporting conventional take-off and landing aircraft introduces new risks. These risks include docking mechanisms, high-strength connectors, and the ability of existing hydrodynamic tools to accurately predict global responses.

The 1995 requirement to support C-17 and other cargo aircraft requires the MOB to be at least 1,500-m (5,000-ft) long (Polky, 1999). Future missions and/or aircraft may push length requirements further. The four major concept designers have considered these moderate length extensions, concluding there are no technical "show stoppers." But clearly there are design penalties such as air gap, structural weight, and required propulsion power associated with greater length.

Metocean Environment

At the beginning of this ONR MOB program, it was unknown if metocean conditions are coherent over lengths that could aggravate MOB structural responses. Due to the unique long length of MOB, metocean design conditions must include spatially significant events such as storm fronts, solitons, tidal currents, and typhoons/hurricanes. These conditions are not normally considered in traditional ocean platform design.

MOB-sponsored studies proved that waves in hurricanes were coherent over lengths equal to the length of a connected MOB (Borgman, et al., 1999), particularly in overall twist/torsion. Other studies showed that existing statistical theories for worst-case and fatigue-basis waves may under predict actual values for structures as long as MOB. The shift from rigid to flexible connectors fortunately reduces the impact of these findings.

A global wave hindcast model is recommended for computing ocean wave and currents at grid points across the entire globe using measured wind/pressure. A grid spacing of 1.25° in latitude by 2.5° in longitude was used to discretize the world's oceans for computing significant wave heights as shown in Figure 2 (Pawsey and Manetas, 1999). Although the program has investigated many unique metocean conditions, these conditions still need to be embodied in a reliability-based design code to support failure mode identification and structural fatigue calculations.

Connector Loads and Global Response

Wave tank testing of original MOB concepts indicated that connector loads would be orders of magnitude beyond the state of practice. Some manufacturing technologies, such as steel plate thickness, are not scaleable, making connectors a critical concept component. The approach taken by the major concept designers has been to trade connector flexibility for load capacity.

For example, McDermott redesigned connectors in their hinged MOB concept (as shown in Figure 3), going from a piano-hinge arrangement (Wu and Mills, 1996) to a compliant plus ball-joint connector arrangement (Haney, 1999). In theory, this greatly reduces loads at the expense of relative roll and yaw. As such, a much smaller, more easily built connector can serve to hold the five semisubmersible modules together to form the 1,500-m (5,000-ft) long runway. The compliant connector is also able to absorb some impact during the connection process and can rapidly connect or disconnect. Aker's concrete/steel hybrid MOB concept uses a similar elastomeric bearing type connector.

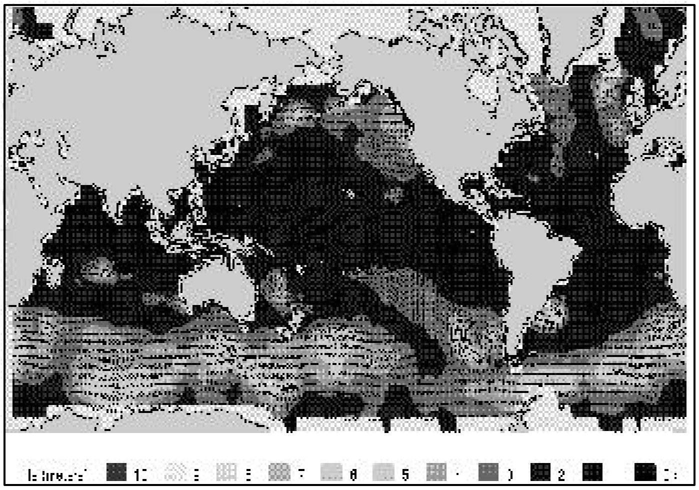

Figure 2. Significant wave heights as computed by a global wave hindcast model.

As another example, Kvaerner created a 'distributed flexibility' connector in their flexible bridge MOB concept (Pettersen, 1999). In theory, this spreads the connector loads over a large cross-section, reducing stress levels in the connector and providing a continuous flight deck, as shown in Figure 4. Damping devices in the flexible bridge provide energy dissipation for flexible modes excited by the ocean wave environment.

On the other hand, Bechtel's independent MOB concept eliminates high strength structural connectors entirely. This concept depends principally on dynamic positioning to hold the semisubmersibles in close relative alignment so that a drawbridge can complete the runway. Figure 1 shows one module of this three-module MOB concept.

The approach of trading reduced connector loads for larger relative motions between modules is rational, provided the resulting misalignment and dynamic motions are less than the maximum allowable for aircraft landing. However, this reduction in loads is not yet proven and demands more accuracy in predicted global responses than is currently available.

The MOB's size and complexity make it impractical to investigate global response by tank or full-scale testing alone. This is particularly impractical for parametric tests to optimize a MOB design. The only reasonable approach is through the use of computer modeling and analysis.

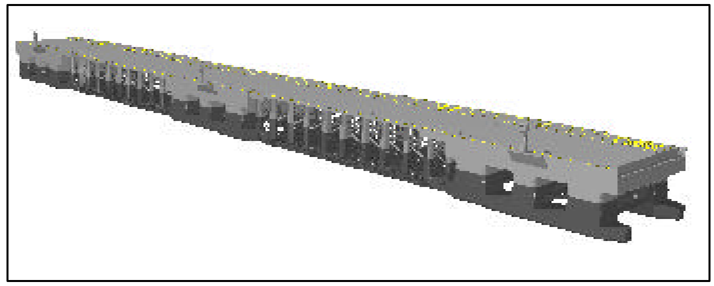

Figure 4. Kvaerner's flexible bridge mobile ocean base concept.

Design Tools and Their Validation

To improve the accuracy of the design/analysis tools, the MOB program has focused tool development in two specific areas: semisubmersible transit stability and computational hydrodynamics and hydroelastics.

Semisubmersibles at transit draft exhibit significant dynamic seakeeping changes as the submersible pontoons are submerged under water. To assure stability, the program undertook a new method of dynamic stability analysis (Falzarano, et al., 1999) with validation model testing.

At transit draft, a MOB semisubmersible module is subject to wave overtopping at the pontoon, as shown in Figure 5 (Kreibel and Wallendorf, 1999). Depending on specific wave height and frequency, a large portion of the pontoon can be overtopped, causing a sudden change in hydrodynamic stability. The dynamic effects associated with this sudden change in waterplane area are now better understood.

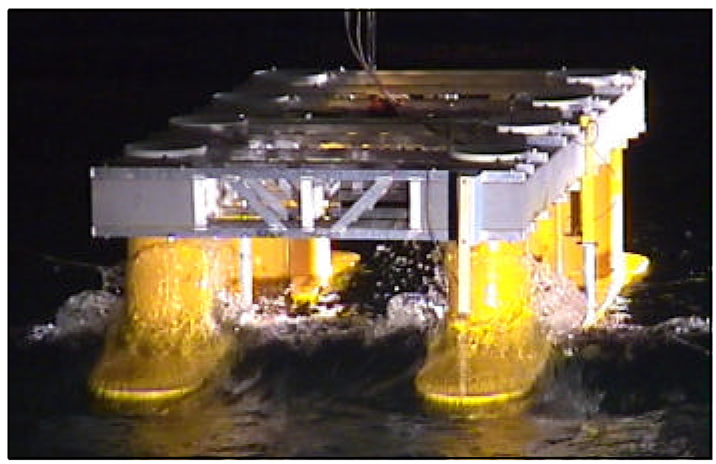

Figure 5. Model test (1:70 scale) of dynamic stability at transit draft.

Figure 3. McDermott's hinged mobile ocean base concept.

The MOB program has benchmarked the state of practice and has improved several commercially available hydrodynamic and hydroelastic codes. These improvements allow these codes to deal effectively with a structure as large and complex as MOB (Zueck, et al., 1999). These code advancements include the following:

- Computational acceleration to speed up simulation (Korsmeyer, et al., 1999).
- Changing boundary conditions to facilitate docking of MOB modules.
- Load generators for automatic input to structural analysis codes.

In addition, time-domain, large-amplitude codes enable investigation of interactive and nonlinear effects such as air gap, wave run-up, and wave patterns affecting at-sea cargo transfer to and from ships along side the MOB.

These improved hydrodynamic and hydroelastic codes have not yet been validated for use in analyzing a structure as large as a MOB. Recently completed hydroelastic model tests (Smith, et al., 1999) provide the necessary data for performing these validations. Figure 6 shows two space-frame modules with end connectors that were used in these hydroelastic model tests.

Designed to qualitatively exaggerate the elastic nature of a MOB hull, the three-dimensional space frame interacts with special elastic connectors to form a complete hydroelastic representation of a generic MOB. The elastic properties of both the hulls and the connectors can be independently adjusted relative to the hydrostatic stiffness to assess the relative importance of hydroelasticity for MOB design. The tests measured module motion, structural strain, connector forces, and water elevation along the length of the MOB. A one-, two-, and four-module MOB was tested, subject to an array of head-on and just-off beam regular and irregular waves. These waves caused the MOB to flex in various bending and twisting modes.

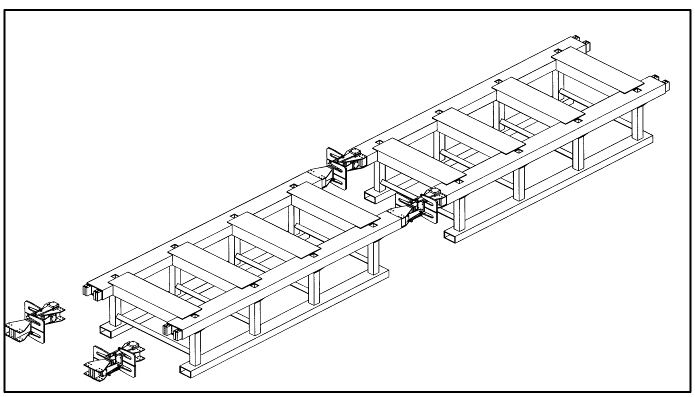

Figure 6. Two modules for use in hydroelastic model (1:60 scale) testing.

Dynamic Positioning

A multi-module dynamic positioning (DP) system is required for propelling, assembling, disassembling, and station keeping of the connected MOB and/or its separable modules. Lacking structural connectors, Bechtel's independent module concept must also depend on robust DP to maintain module alignment relative to one another when functionally 'connected.' DP systems can be divided into two convenient parts: the propulsion hardware and the control software.

The current state-of-practice for DP consists of the installation of two to six 7,500-kW (10,00-hp) thrusters in a floating structure to maintain absolute position relative to a fixed location such as a drill hole. Each MOB module will possess up to ten 19,000-kW (25,000-hp) thrusters that must reliably maintain close relative position to adjacent modules that themselves are moving. Fortunately the cruise industry is currently pioneering the development of large horsepower electric-drive azimuthing thrusters that are ideal as propulsion hardware for the MOB.

However, the need still exists for control software that can direct up to eight thrusters located on each of up to six MOB modules. This software must uniquely prevent damage while docking, adapt to mechanical failures on an adjourning module, and counter multi-body string instability due to spatially varying environmental disturbances along the length of the MOB. Even the sensor package that provides sensory input to this control software is a challenge, as metocean conditions may vary substantially from one end of an assembled MOB to the other.

As such, the MOB program has extended traditional DP software to control a multi-module MOB, developing a new hierarchical control architecture and building a simulation tool for testing the possible linear and nonlinear control theories (Girard and Hedrick, 1999). In addition, the program will evaluate all the DP software and its ability to control the close relative position of a string of semisubmersible modules using a physical multi-module experiment as shown in Figure 7. The unique experiment features global and relative position measurement, disturbance mechanisms, interchangeable control logic, and azimuthing small-scale thrusters.

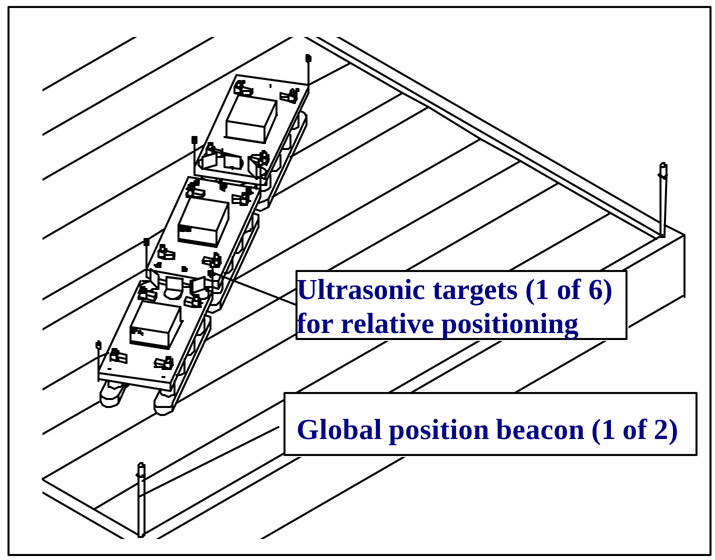

Figure 7. Position sensors for DP model (1:150 scale) testing.

Constructibility

At approximately 300,000 metric tons of displacement, even the smallest of the proposed MOB semisubmersible modules is an order of magnitude larger than any existing floating structure. However, fixed structures of comparable size have been built, and the techniques for offshore assembly of major fabricated assemblies into finished platforms have been demonstrated. A risk-based constructability analysis (Bender, et al., 1999) shows that MOB modules can be built in the United States using a combination of onshore and offshore facilities. Alternatively, complete MOB modules can be fabricated using a dedicated onshore facility (Rognas, et al., 1999). Therefore, constructibility is no longer a feasibility issue for MOB.

Survivability and Explosive Safety

This threat addresses responses to weapons-induced, high-pressure waves that typically buckle and tear hull shell plating. A properly located explosion will "break the back" of a normal ship, reducing hull girder strength to a small fraction of that needed for even calm water. Semisubmersible hull forms are far more resistant to this type of attack, since localized pontoon buckling does not affect the deckhouse; hence hull girder strength is reduced by only a small fraction. Most of the column and pontoon boundary tanks are used for ballast or fuel; hence, puncture may not change the level of submergence.

MOB could store munitions for aircraft and ground equipment. Such munitions can detonate from fire, shock, and hostile action. Logistic assets typically have no resistance to internal explosions, and floating combatants cannot typically operate after or survive a magazine explosion. However, the MOB's size and arrangement have the potential to meet land-based explosive safety requirements through a combination of physical separation, non-propagation walls, and venting explosive pressures downward below the deck. This is similar to the way petroleum producers currently minimize damage from offshore explosions.

Cargo Transfer Ability

The primary mission requirement for the MOB is to store and transfer cargo as a logistics facility. The program has developed specific tools and techniques for quantifying how well the MOB satisfies given mission requirements. For example, there is an operational availability model to predict the percentage of time the MOB can perform its key mission requirements. This model correlates hindcasted environmental data for a specific site and season with at-sea operations related to a specific platform configuration to estimate the statistical cargo throughput effectiveness (Jha, et al., 1999).

The effectiveness of open-sea cargo transfer depends heavily on the high relative motion between the transferring vessels. Given the lesser metocean conditions when cargo transfer is desired, a very large semisubmersible like MOB does not move much, thus minimizing the open-sea cargo transfer problem. However, recent hydrodynamic studies have indicated that waves radiating from the large semisubmersible columns of a MOB amplify the normally rough seas and could greatly hinder cargo transfer to and from smaller vessels alongside the MOB (Lundberg and Grant, 1999).

Figure 8 shows an example wave pattern created around and within a MOB module with regular 6-second waves approaching at a 30° heading. Values greater than one indicate amplification of the incoming wave field. Depending on specific incoming wave frequency and heading, wave amplification can occur even on the leeward side of the MOB.

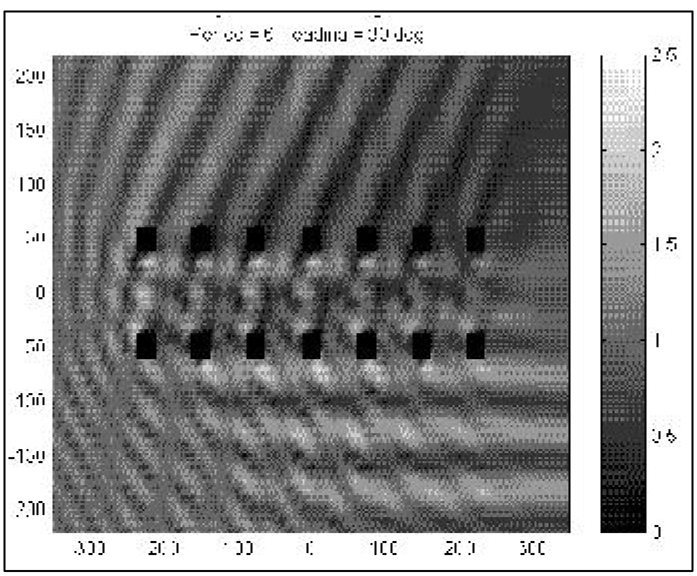

Figure 8. Ocean wave patterns around a single MOB module.

Some potential solutions have been proposed, including methods of forming a protected harbor, lifting smaller vessels out of the water, and improving the motion compensation capability of handling equipment.

Technical Feasibility

Deciding when a particular concept or product is technically feasible is a subjective judgment. The S&T program has brought us much closer to that point. Mission requirements have been deconstructed into design criteria, augmented as necessary with specific studies to determine such basic parameters as size, speed, and general configuration. Environmental requirements have been defined, and a fundamental design procedure has been developed to establish structural reliability. Stability and hydrodynamic tools have been developed, improved, and applied to MOB concepts, and although those tools need to be validated against model tests, the general approach has been successful in offshore mooring designs. Viable construction procedures have been advanced for building the large MOB modules, and the scope of work has been determined to be within the abilities of the United States' shipbuilding industry. The consensus of the contractors involved with MOB is that MOB is indeed technically feasible, provided that future hydrodynamic analysis confirms satisfactory global response in the presence of long-period waves.

CONCLUSIONS

The MOB program has successfully addressed all key technology issues and resolved most of them to a level considered adequate for establishing that the concept of a MOB is feasible. In summary, these issues and their state of current resolution is as follows:

- MOB's large size is not by itself a problem if existing design standards are adjusted to recognize the effects of long length. However, the MOB design guide needs to be exercised to establish target reliabilities and other design criteria.

- Due to MOB's potentially long length, the spatial variability in the metocean environment becomes important. The basics for such a unique look at the metocean environment are now available.

- The spatially variable long crested waves can cause uncommon connector forces and global response. Work is continuing on assessing the level of interaction between connector forces and global response. Results are quite encouraging.

- Existing hydroelastic modeling tools have been modified to help better understand this interaction. However, these modified tools have yet to be validated against the recently collected MOB hydroelastic test data.

- A multi-module dynamic positioning system has been developed to control MOB's uncommon motions. Experimental tests are ongoing to validate this new use of nonlinear control logic.

- Constructibility in either concrete and/or steel is essentially assured.

- The issue of survivability and explosive safety is equal to or often less than for traditional military logistics options.

The MOB program has brought the offshore industry and academia into hitherto unknown territory and has acted as a rallying point for pushing many technological boundaries. The program was run with an "open architecture," which included semi-annual meetings to present research results and share information. The technical fundamentals for many of the conclusions drawn here have been published in the technical literature, including several other papers in this conference proceeding. In addition, over 350 technical documents generated by the MOB program are available at the MOB Internet site, http://mob.nfesc.navy.mil.

Due to the short time frame of this program there was insufficient time to complete certain tasks that are important to any future MOB development effort, should a decision be made to continue towards acquisition. Chief among these efforts is the need to complete the hydrodynamic code validation efforts, which are key to the prediction of global response.

MOB would be a totally new type of military and humanitarian support asset. It would remove the need for a large footprint to launch or support force deployments. It would create an at-sea location for the difficult break-bulk operations needed to support highly mobile, light combat units and to enable sea-based support for lengthy sustenance. It could move forward to follow the battle, removing the historical concern attendant to long logistics lines. It could move from trouble spot to trouble spot, carrying and supporting military personnel and materiel in either combat or humanitarian/relief operations, wherever they are needed, minimizing the presently irretrievable costs of building land bases.

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